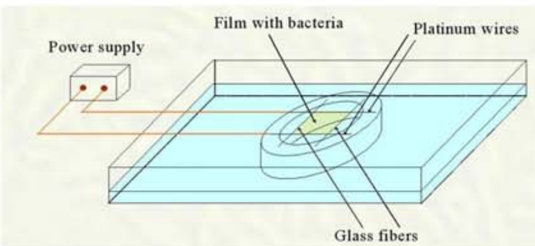
Emergent Behavior and Hydrodynamics of Active Bioparticles

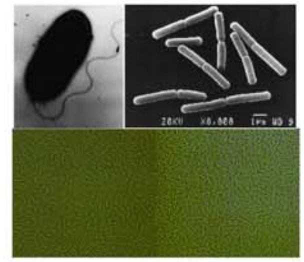
Andrey Sokolov[a], Igor Aronson[a], Ray Goldstein[b], and John Kessler[b]
[a] Materials Science Division, Argonne National Laboratory
[b] Department of Physics, University of Arizona

Bacillus subtilis are flagellated, rod-shaped micro-organisms, 5-10 microns long and capable of swimming up to 20 microns/second. The hydrodynamic and chemical interactions between individual cells results in remarkably rich emergent behavior; self-concentration due to gradients of dissolved oxygen or pH level; phase transitions and self-organization in confined geometries. This self-organization often takes the form of coherent structures with typical sizes that are many times larger than those of the individual bacteria. We present a new way to control the density of bacteria and separate living from dead cells.

Experimental Setup

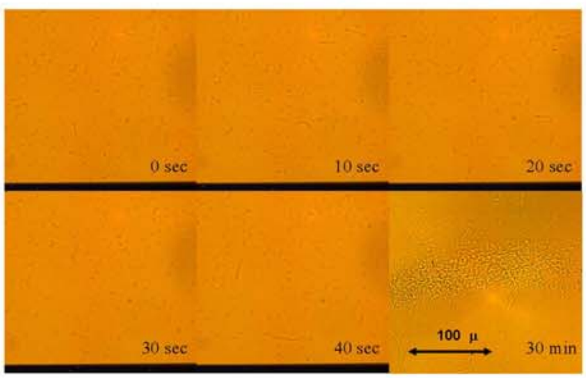


A thin liquid film with bacteria is spanned on two glass fibers and two platinum wires. The cell is enclosed in a container with controlled humidity. The thickness of the film is controlled by displacement of the supporting rods.



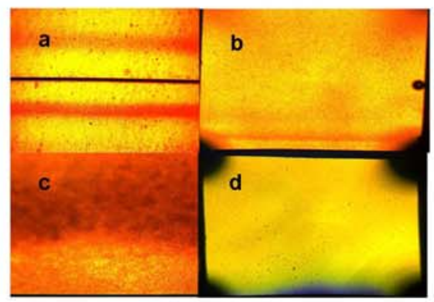
SEM images of individual bacteria (top). Monolayer of dense suspension of bacteria

Concentration and Sorting of bacteria by electric current



Current-induced concentration of bacteria in thin fluid film

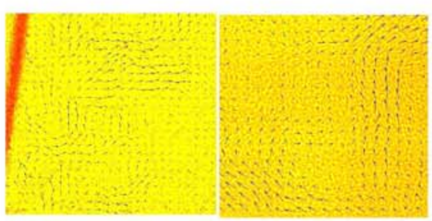
Electric current forces living cells to concentrate in a thin band between two electrodes, while dead cells remain immobilized. This effect can be used for separation and segregation of dead/live cells. The local change of pH level near the electrodes forces live bacteria to migrate to areas with favorable pH level (7.2 pH).



Layers of bacteria on each side of the electrode (a,b), spot formation in dense colonies (c), distribution of pH, blue color correspond to a higher pH level (d).

Large-scale dynamics of bacteria

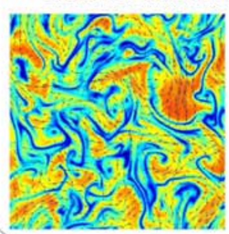
Swimming bacteria stir up the fluid and affect their neighbors. Synchronized motion of flagella creates organized large-scale jets and vortices. The collective velocity of bacteria reaches up to 100 μm/sec.



Bioturbulence in a thin bio-layer in the presence of an oxygen gradient (left); self-organized bacterial flows in a thin film experiment (right). The background color image shows bacteria density.

Mathematical model

- Equation for local bacteria orientation
- 2D Navier-Stokes equation for fluid
- Self-propelled particles create flow in the film
- Instability mechanism: shear flow alters bacteria orientation which in turn accelerates the flow



Large-scale turbulent structures

Colors: degree of orientation (red color corresponds to a higher degree of orientation)

Arrows: fluid velocity field

Future plans

- quantitative exploration of biofluid dynamics in confined geometries
- comparison of experimental results with mathematical model
- modification of bacteria mobility due to attached particles
- extension to different types of bacteria and microorganisms

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